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Los Alamos
NATIONAL LABORATORY
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A few Los Alamos Nuclear Safeguards stories and other things

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ANU, Canberra, 8th November 2012

1991-1993 Physics Division, Neutron Science and Technology Group, Weapons Nuclear Research

1998-2004 Nuclear Non-Proliferation Division

2004-2012 Computation Physics & Theoretical Design Divisions, Particle transport applications group.

Abstract

Two very different nuclear material safeguard missions will be briefly described to give the audience a feel for the type of work carried out by physicists at the Los Alamos National Laboratory. I will show how transit-state theory can be used to derive black-body radiation and the escape of particles from an ideal gas. Understanding these simple processes can led to a better understanding of how transit-state theory should be applied in the theory of nuclear reactions. Finally I will show a few photos to give a feel for some of the other missions conducted by Los Alamos.


10/27/2012

To succeed at Los Alamos you need to be a “Jack of all trades”.

Los Alamos 1998-2012

Rock Flats Tomographic Gamma-ray Scanner
Kazakhstan Safeguards
Vinca reactor (Serbia) nuclear materials evaluation
Weapons diagnostics (over 20 NTS events)
Emergence Response
Fission neutron multiplicity distributions
TITANS (Student and Teacher)
Neutron initiation
Radiography
Certification of new W88 primary
Certification of the W88 secondary
Modeling of U,Pu(n,f) fission mass and TKE distribution, and n-n correlations
W78 aging issues

Transition State Theory and Langevin based nuclear dynamics

- Heavy-ion fusion-fission reactions
- Ternary fission
- HBT effect
- Hawking radiation (black holes)

Pyrochemical Salts at RFETS

"Building 371 is the nation's premier producer of nuclear garbage."

Closure target: 2006

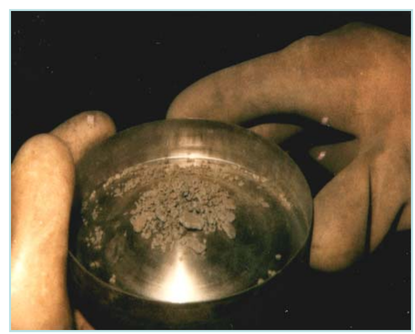
Nondestructive assay is a major bottleneck (required for disposal at WIPP).

One of the most challenging waste forms is pyrochemical salts (≈ 16,000 kg).

- Impure (Pu & ^{241}Am), heterogeneous, contains metal shot

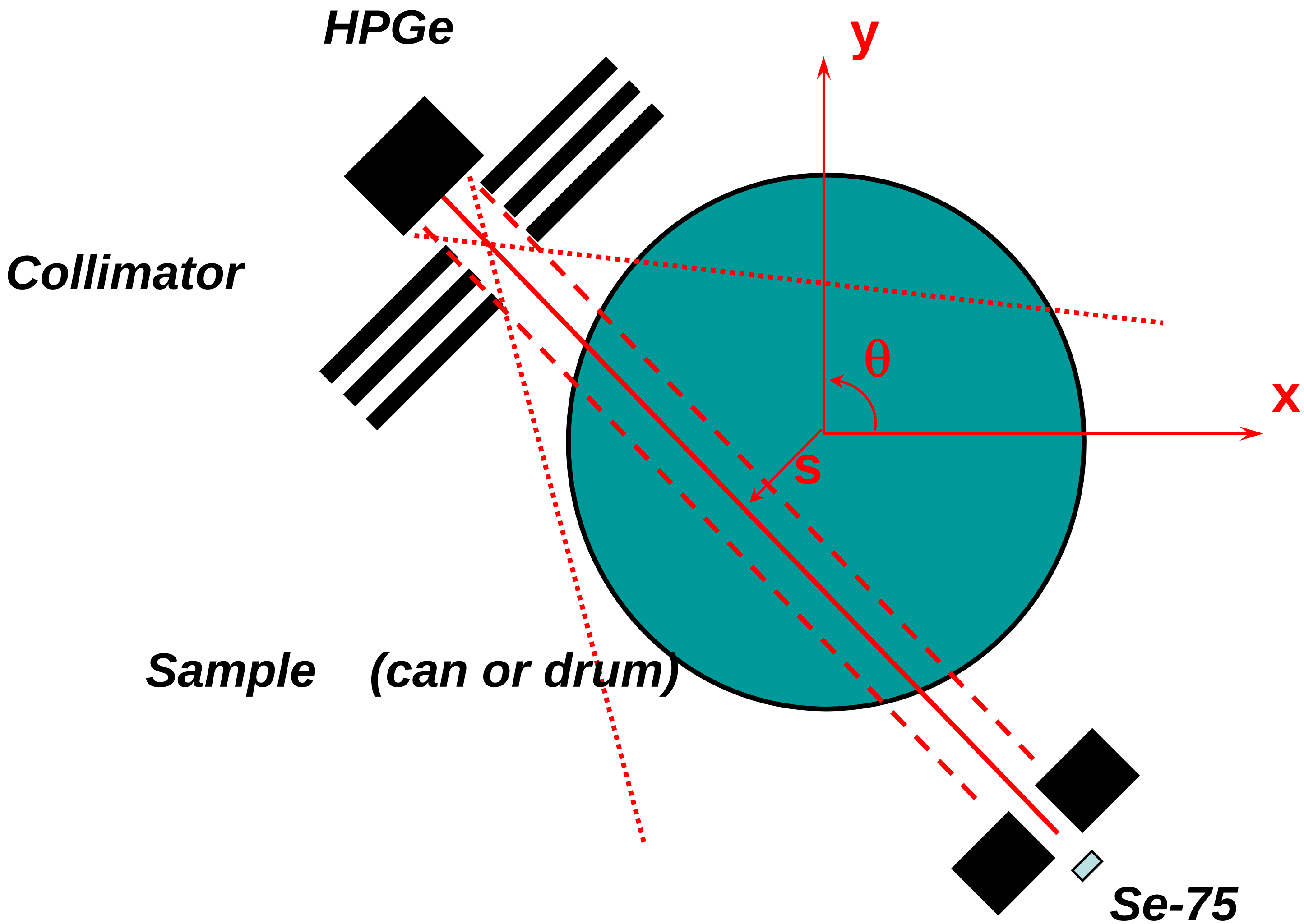
salt

crush & sieve



metal shot

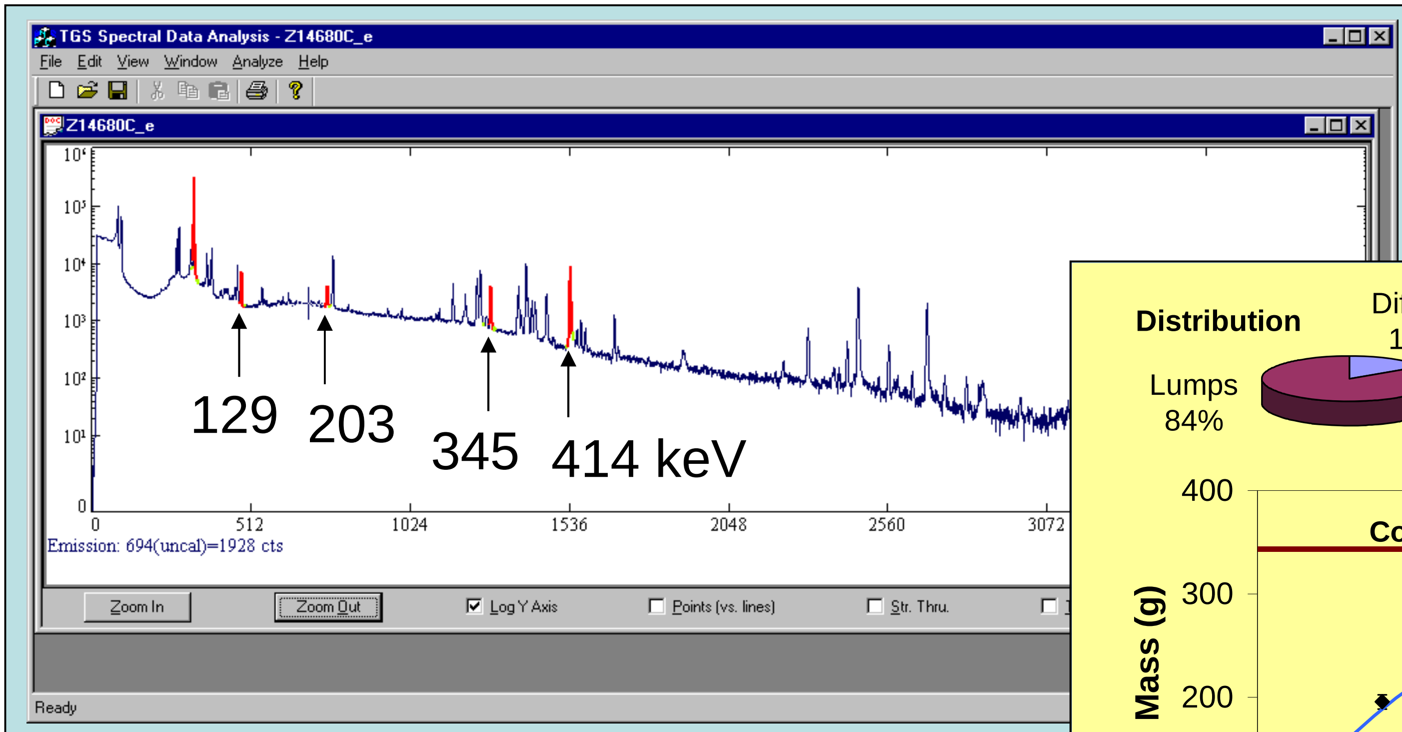
Tomographic Gamma Scanning basics



Skid-Mounted TGS

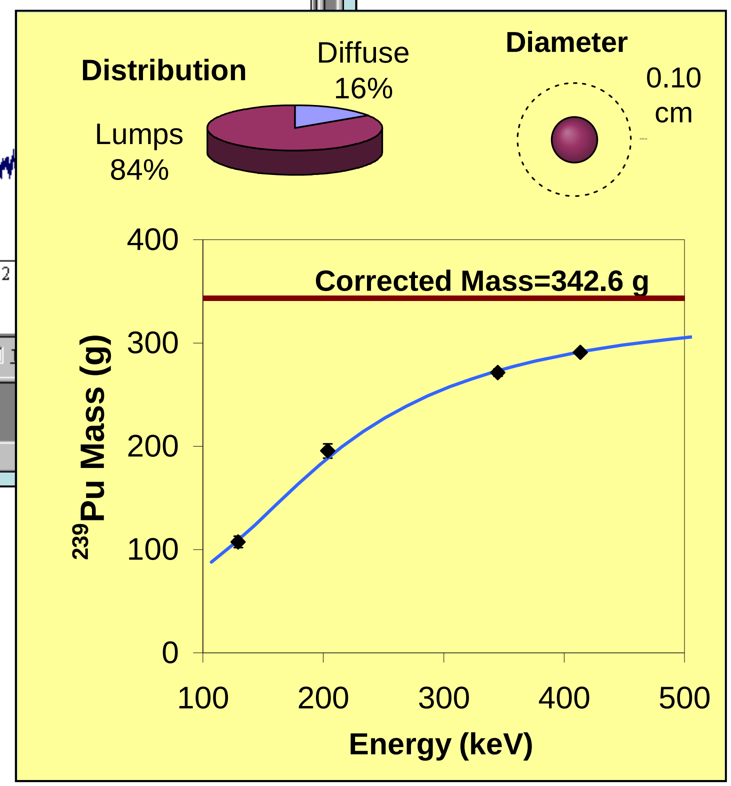
Software Improvements

- Faster, PC-based analysis
- Simpler to use
- Whole-spectrum capture (4800 spectra in 45-min. scan)

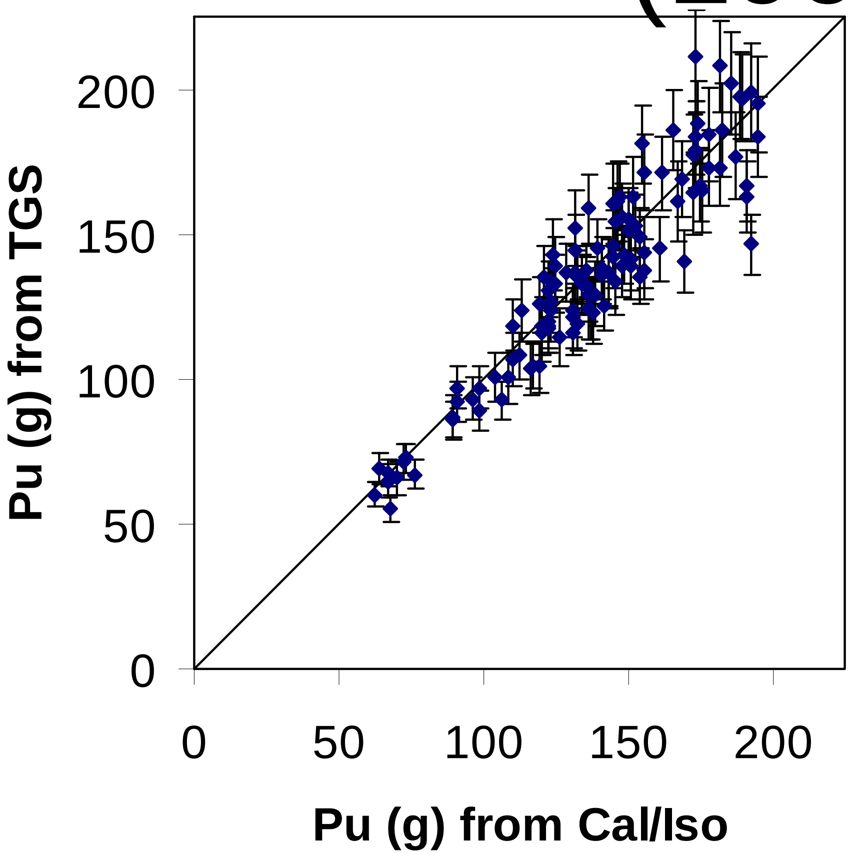


- Automated lump corrections →

Example: Uncorrected Mass = 290.9 g
Corrected Mass = 342.6 g
Known (Cal/Iso) = 349.0 g



Skid TGS Measurement of Salts (1999-2000)



From 209 verification runs:

•Uncertainty per meas. = 9.4%

•Inventory Bias = (-0.04 ±0.99)%

13.461 kg (TGS)

13.467 kg (Cal/Iso)

Unexpected challenges:

•High background

•Added Sn shielding

•Severed PUR cable

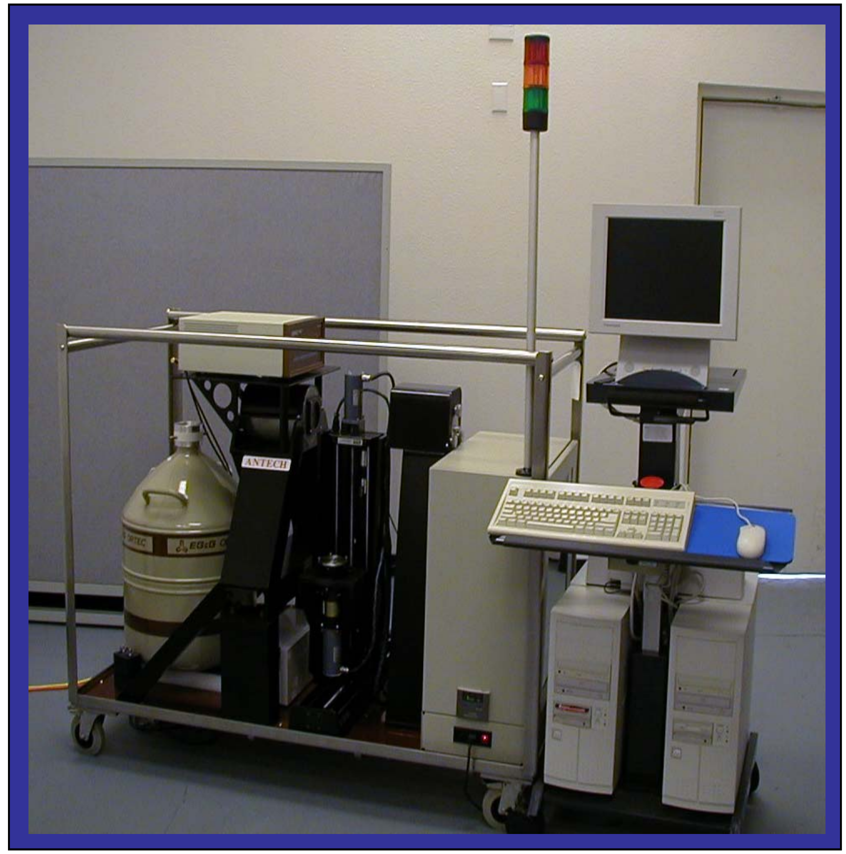
Throughput:

10-20 items/day

Commercialization

Technology licensed to ANTECH, BNFL, and ORTEC

ANTECH Drum TGS



ANTECH Can TGS

The Caucasus and Central Asia

BN-350 Aqtau, Kazakhstan

SFCC : Installed in October 1998 and
removed from the pond in October 2001

SFCC can directly measure the plutonium content of spent fuel with low levels of Cm (Breeder and plutonium production spent fuels).

~3000 spent fuel items have been measured in the BN-350 spent fuel pond in Aqtau, Kazakhstan. These include:

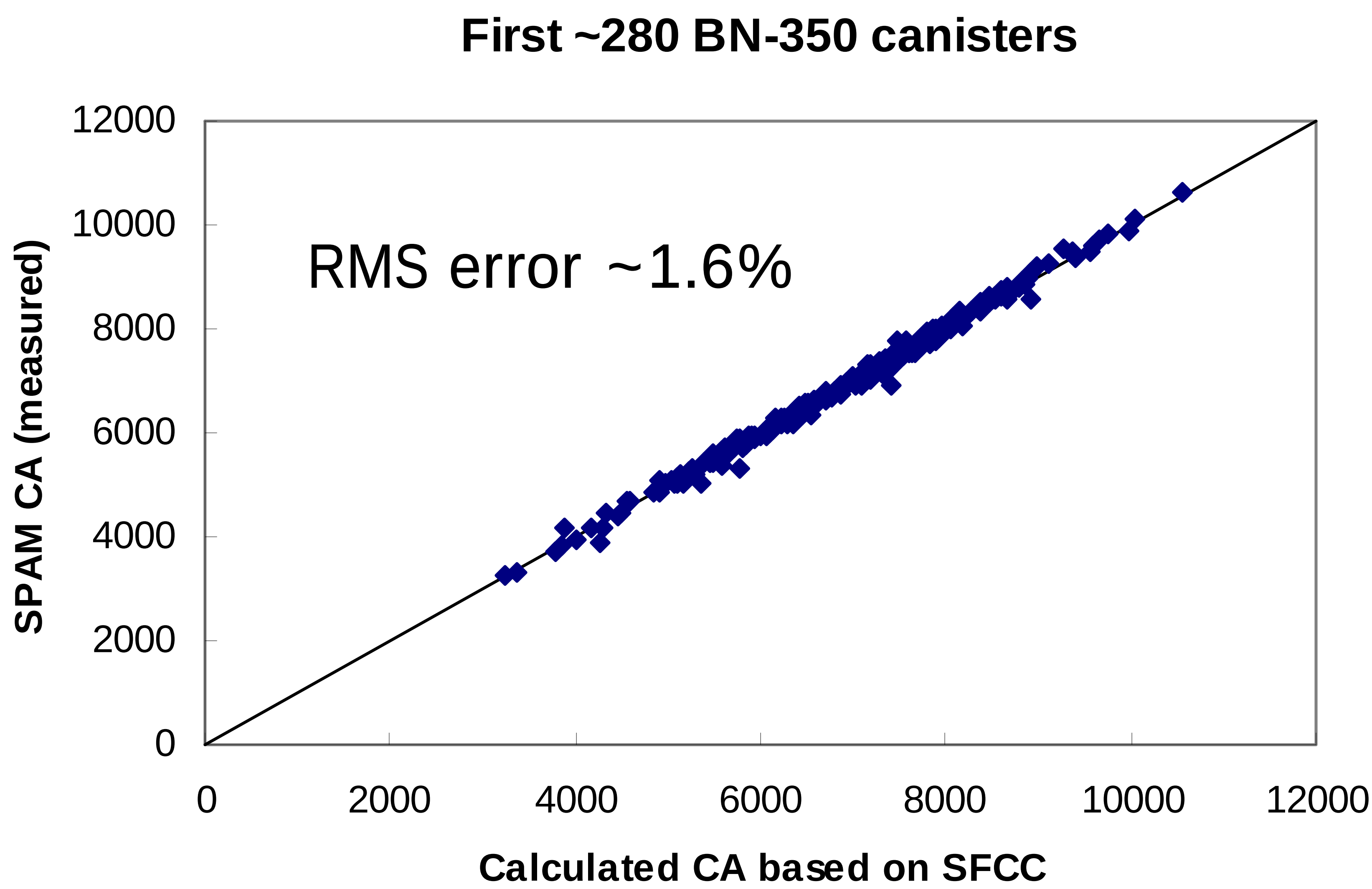
- Assemblies with radiation levels up to 150,000 R/h at contact.
- Burnups up to 50000 MWd/t.
- Enriched spent fuels with ^{235}U enrichments up to 26%
- Blanket assemblies
- Leaking assemblies placed in over-packs
- Partial assemblies
- Single fuel pins
- Three different types of control assemblies/rods
- MOX fuel assemblies
- Metal fuel assemblies

Summary of the first ~1600 items measured with the SFCC

Difference between measured and declared ~ 0.4%

NIMA **490** pp 409-425, Sep 2002

SPAM installation in October 2001



First ~280 BN-350 canisters
RMS error ~1.6%
SPAM CA (measured)
Calculated CA based on SFCC
0
2000
4000
6000
8000
10000
12000

Bohr-Wheeler Transition State Theory

First used to determine fission probabilities in 1939

One of the most beautiful consequences of quantum mechanics is that the mean time for an equilibrated system to find a specific configuration is given by

$$\bar{\tau} = h \cdot \rho_i$$

This is one of the great laws of physics and should be held in the same reverence as

$$\lambda = \frac{h}{p}$$

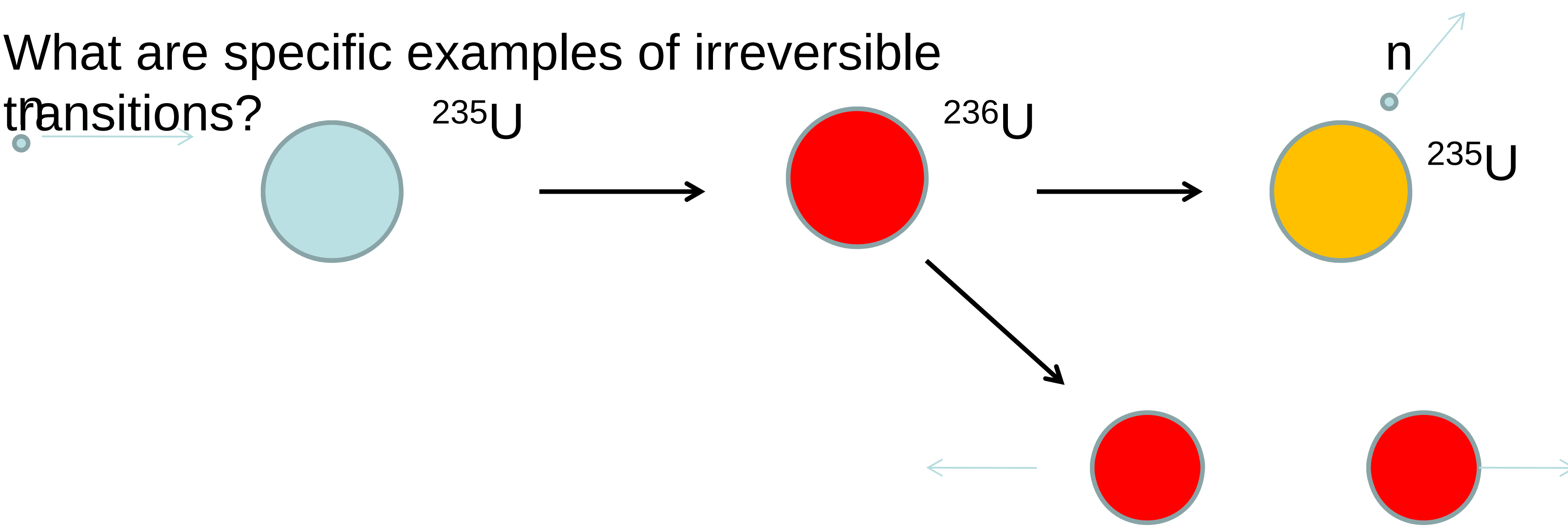
The mean time for a system to make an irreversible transition is given by

$$\bar{\tau} = \frac{h \cdot \rho_i}{N_{\mathrm{TS}}}$$

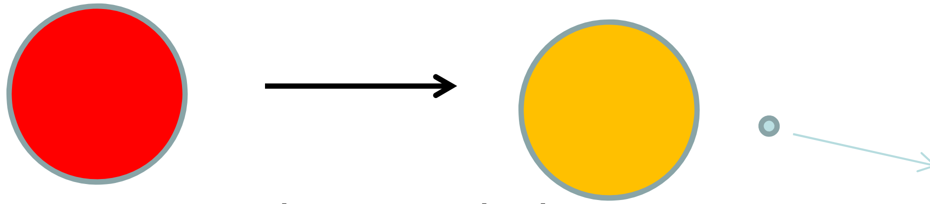
The probability per unit time that a system makes an irreversible transition is given by

$$\lambda = \frac{1}{\bar{\tau}} = \frac{N_{\mathrm{TS}}}{h \cdot \rho_i}$$

What are specific examples of irreversible transitions?

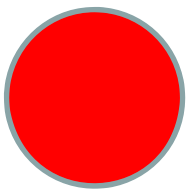


In general

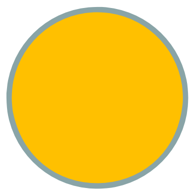


Black body	photon emission
Ideal gas	emission of particles
Atomic nucleus	fission and the emission of neutrons, alpha particles etc
Black hole	Hawking radiation
Globular cluster	Star emission

Black body radiation



$$\rho_i(U_i)$$

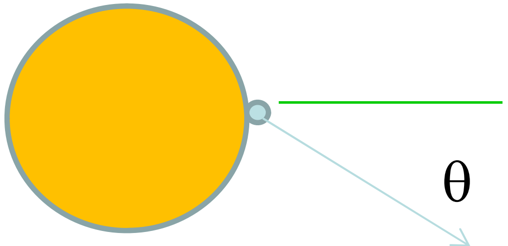


$$\rho_f(U_i-\varepsilon)=\rho_i(U_i)\exp(-\varepsilon/T)$$

Assuming that all photons are emitted perpendicular to the surface of a spherically symmetric object(L=0) then the number of transition states associated with the emission of photons from ε to ε + dε is given by

$$N_{\mathrm{TS}}=\rho_f(U_i-\varepsilon)\,d\varepsilon=\rho_i(U_i)\exp(-\varepsilon/T)d\varepsilon$$

$$\lambda(\varepsilon,L=0)=\frac{N_{\mathrm{TS}}}{h\cdot\rho_i}=\frac{\rho_i\exp(-\varepsilon/T)\,d\varepsilon}{h\cdot\rho_i}$$



Emitted photons can have an orbital angular momentum quantum number that is not zero.

In the classical limit this gives

$$\lambda(\varepsilon) = \frac{(1+3+...+L_{\max})\exp(-\varepsilon/T)\,d\varepsilon}{h}$$

$$\lambda(\varepsilon) = \frac{L_{\max}^2\exp(-\varepsilon/T)\,d\varepsilon}{h}$$

The maximum orbital angular momentum that a photon can carry is

$$L_{\max}\hbar = \frac{\varepsilon}{c}\cdot r \quad \text{and therefore} \quad L_{\max}^2 = \left(\frac{\varepsilon\, r}{\hbar c}\right)^2$$

$$\lambda(\varepsilon) = \frac{L_{\max}^2 \exp(-\varepsilon / T)\, d\varepsilon}{h} = \frac{1}{h}\frac{\varepsilon^2 r^2}{\hbar^2 c^2}\exp(-\varepsilon / T)\, d\varepsilon$$

$$= \frac{1}{2\pi}\frac{\varepsilon^2}{\hbar^3 c^2}\frac{4\pi r^2}{4\pi}\exp(-\varepsilon / T)\, d\varepsilon$$

$$= \frac{A_s}{8\pi^2}\frac{\varepsilon^2}{\hbar^3 c^2}\exp(-\varepsilon / T)\, d\varepsilon$$

$$P = \int_{\varepsilon=0}^{\infty}\frac{A_s}{8\pi^2}\frac{\varepsilon^3}{\hbar^3 c^2}\exp(-\varepsilon / T)\, d\varepsilon$$

$$P = \int_{\varepsilon=0}^{\infty} \frac{A_s}{8\pi^2} \frac{\varepsilon^3}{\hbar^3 c^2} \exp(-\varepsilon / T)\, d\varepsilon$$

For the emission of mass-less particles one needs to replace

$$\exp(-\varepsilon / T) \ \text{ with } \ \frac{1}{\exp(\varepsilon / T) \pm 1}$$

Lestone, Mod. Phys. Lett. A, **23**, 1067 (2008)

$$P = \int_{\varepsilon=0}^{\infty} \frac{A_s}{8\pi^2} \frac{\varepsilon^3}{\hbar^3 c^2} \frac{1}{\exp(\varepsilon / T) - 1}\, d\varepsilon$$

$$= \frac{A_s}{8\pi^2} \frac{1}{\hbar^3 c^2} \frac{\pi^4 T^4}{15} = A_s \frac{\pi^2 k^4}{120 \hbar^3 c^2} T^4$$

Photons have two states of helicity (left and right) or, if you like, two states of polarization.

$$P = A_s \sigma T^4, \quad \sigma = \frac{\pi^2 k^4}{60 \hbar^3 c^2} = 5.7 \times 10^{-8} \frac{W}{m^2 K^4}$$

Understanding black body radiation

$$\lambda(\varepsilon) = \frac{L_{\max}^2 \exp(-\varepsilon/T)\, d\varepsilon}{h} \qquad p = \frac{\varepsilon}{c}$$

Stimulated emission Two states of helicity

What about the emission of particles from an ideal gas? $p = \sqrt{2m\varepsilon}$

$$\text{replace } \frac{\varepsilon^2}{c^2} \text{ with } 2m\varepsilon$$

$$\lambda_{\text{bb}}(\varepsilon) = \frac{A_s}{8\pi^2} \frac{\varepsilon^2}{\hbar^3 c^2} \exp(-\varepsilon/T)\, d\varepsilon$$

$$\lambda_{\text{ig}}(\varepsilon) = \frac{A}{8\pi^2} \frac{2m}{\hbar^3} \varepsilon \exp(-\varepsilon/T)\, d\varepsilon \neq A \frac{n}{T\sqrt{2\pi m T}} \varepsilon \exp(-\varepsilon/T)\, d\varepsilon$$

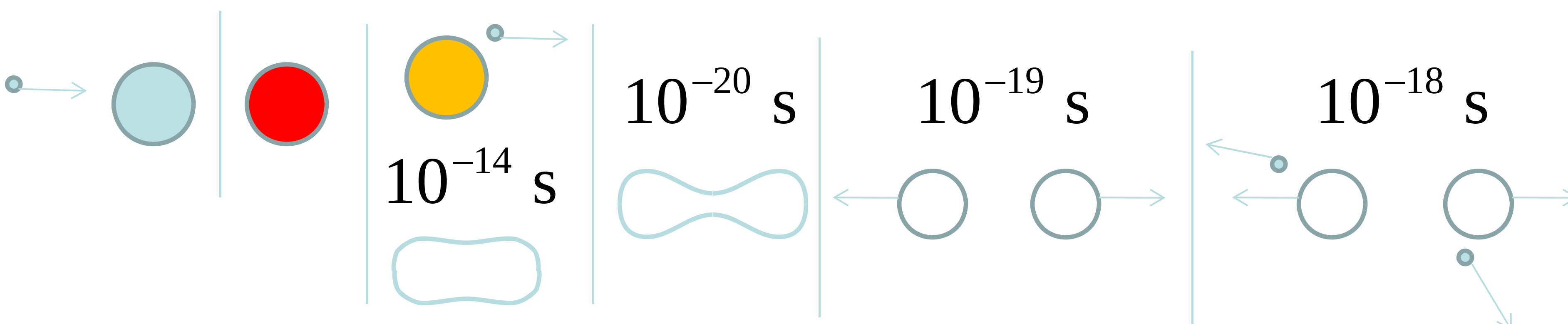
Why has our logic failed?

$$\rho_f(U_i-\varepsilon, N-1)=\rho_i(U_i, N)\exp(-\varepsilon/T)\cdot n\hbar^3\left(\frac{2\pi}{mT}\right)^{3/2}$$

$$\lambda_{\mathrm{ig}}(\varepsilon)=\frac{A}{8\pi^2}\frac{2m}{\hbar^3}\varepsilon\exp(-\varepsilon/T)\,d\varepsilon\;n\hbar^3\left(\frac{2\pi}{mT}\right)^{3/2}$$

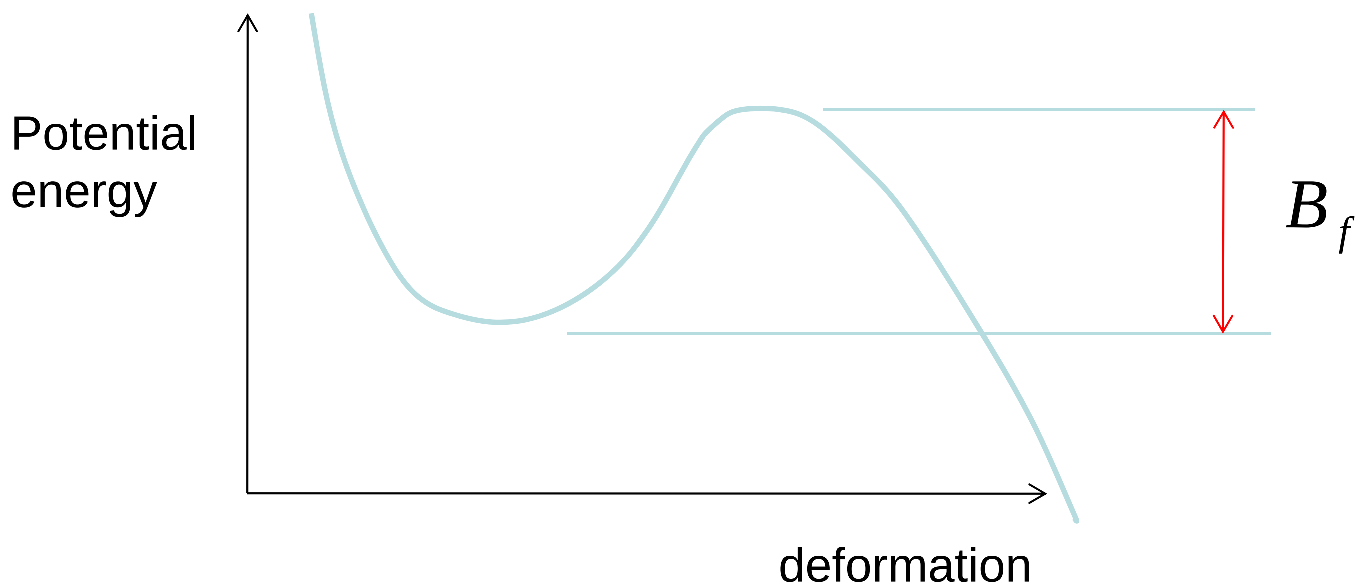
$$=A\frac{n}{T\sqrt{2\pi mT}}\varepsilon\exp(-\varepsilon/T)\,d\varepsilon$$

What has all this got to do with nuclear physics?



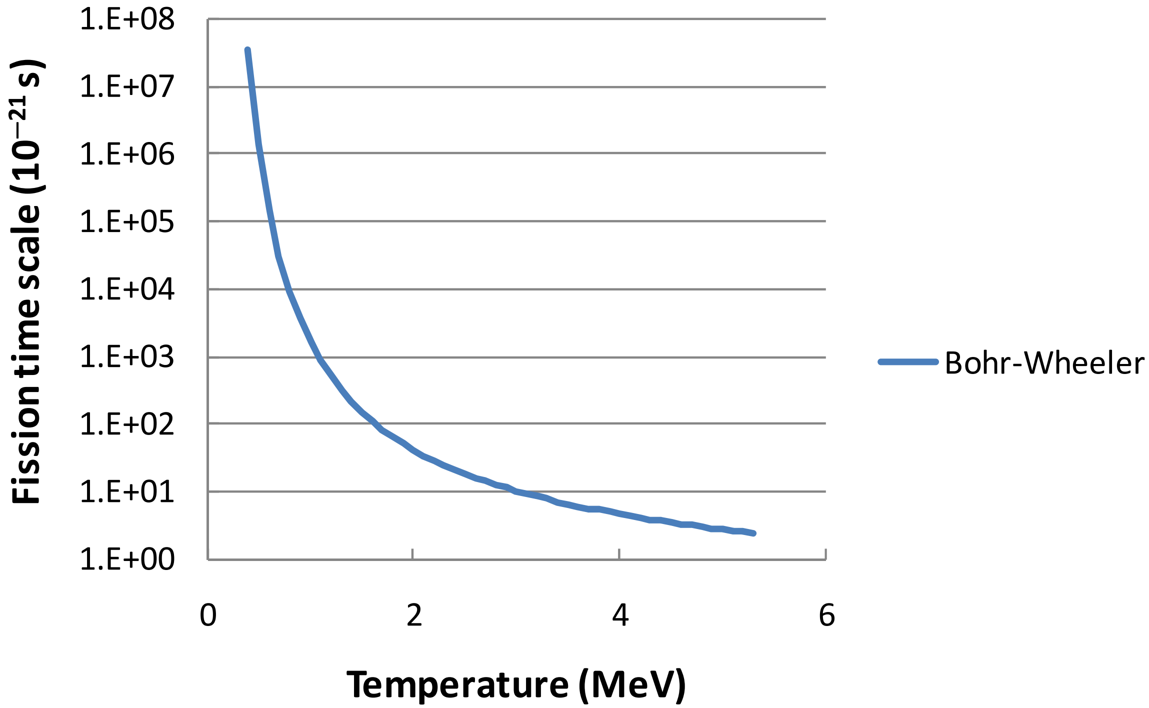
Time scale for fission

$$\lambda_{\mathrm{BW}} \sim \frac{T}{2\pi\hbar}\exp(-B_f/T)$$



$$\lambda_c \sim \frac{\omega}{2\pi}\exp(-B_f/T)$$

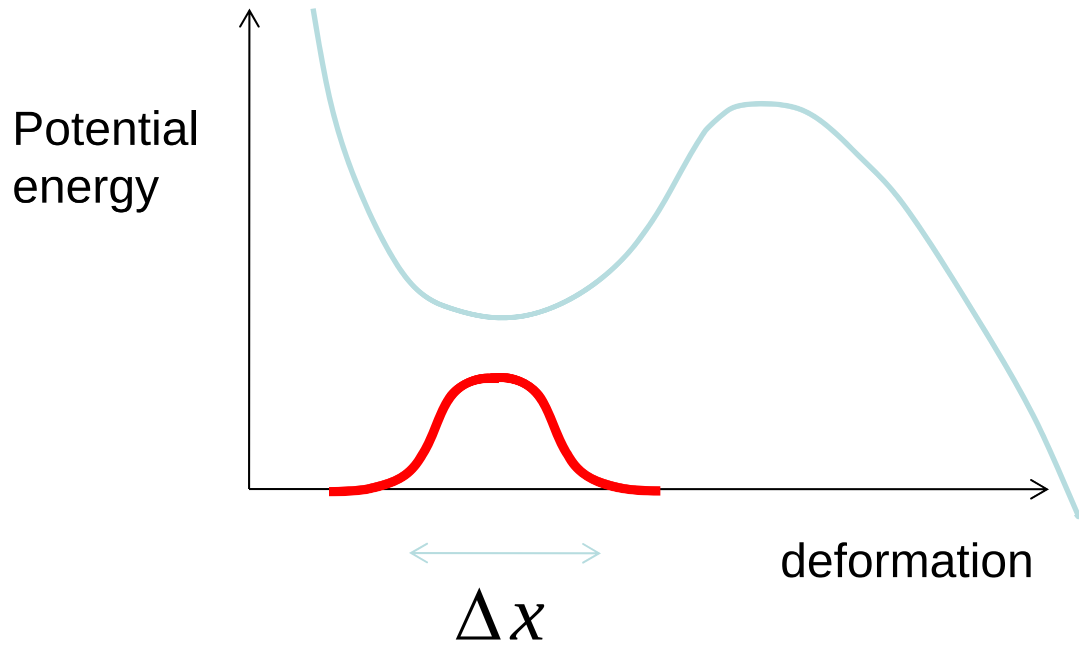
$$\bar{\tau}_{\mathrm{BW}} \sim \frac{2\pi\hbar}{T}\exp(B_f/T) \sim \frac{4.1\times10^{-21}\ \mathrm{s\cdot MeV}}{T}\exp(B_f/T)$$



From experiment we know this theory fails at temperatures above 1 MeV.

$$\rho_{\mathrm{FTS}}\left(U_i-\varepsilon\right)=\rho_i(U_i)\exp(-\varepsilon/T)$$

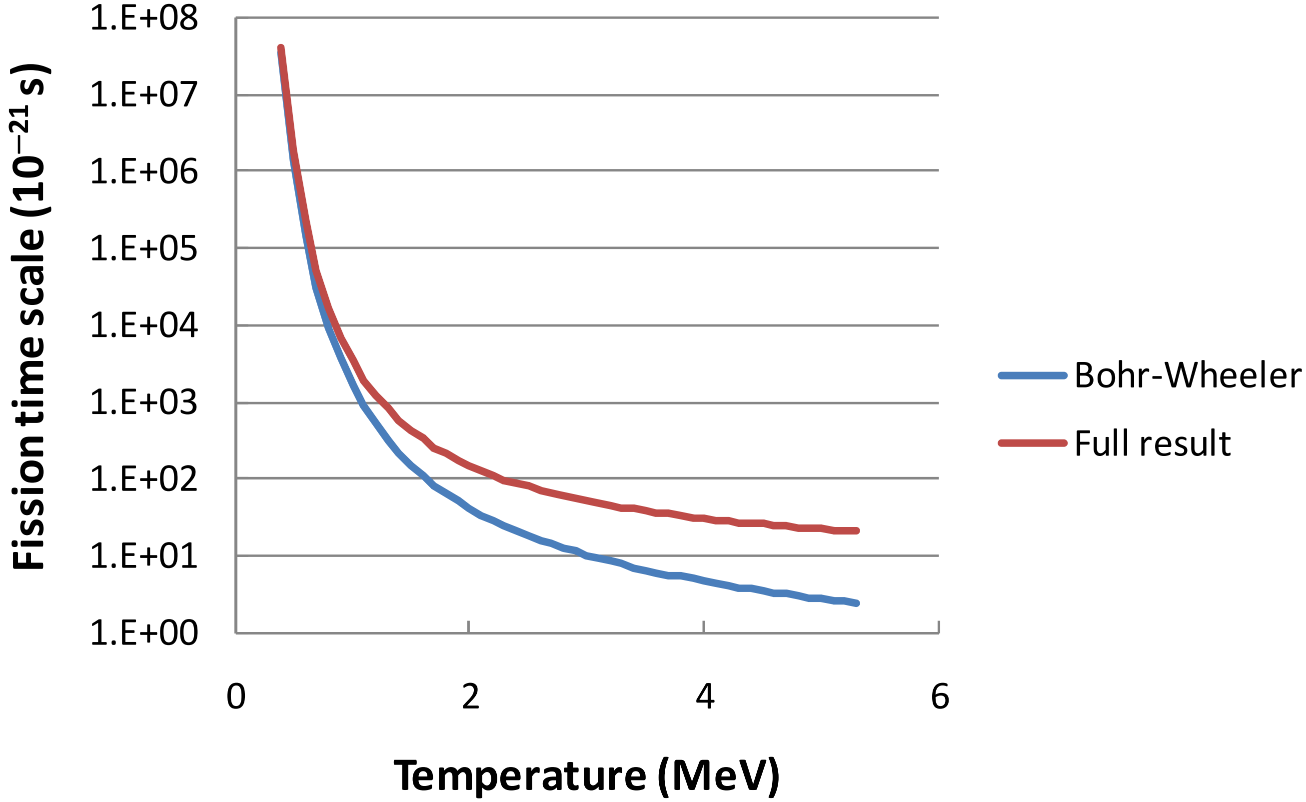
This is only valid at low temperatures where the characteristic length scale defining the distribution of nuclear shapes (deformations) is controlled by quantum mechanics.



The length scale over which the collective motion moves is independent of temperature when $T << \hbar\omega$

However, when the temperature is larger than $\hbar\omega$, then the length scale over which the collective motion moves, increases nearly linearly with increasing temperature.

$$\bar{\tau}_f \sim \frac{2\pi\hbar}{T}\frac{\exp(B_f/T)}{1-\exp(-\hbar\omega/T)}$$



McCalla and Lestone Phys. Rev. Lett. **101**, 032702 (2008),
Lestone and McCalla Phys. Rev. C **79**, 044611 (2009)


MUSEUM
Fat Man
Parts of the Bomb
How it works
Countdown to Nagasaki
10/27/2012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Explosives Experiments in the Containment Chamber
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